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INTRODUCTION TO THE SCENE MATCHING MISSILE
GUIDANCE TECHNOLOGIES

by

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Introduction to the Scene Matching Missile Guidance Technologies

Shi-Xue Tsai

During the Gulf war of 1992, Tomahawk BGM-109 cruise missile launched from off-shore battleship was been deployed by the allied force to carry out the first attack to Iraq's strategic targets. That was also the first time of using this new kind of missile in the real war after it was been developed. Among the 280 Tomahawk missiles that have been launched, the percentage of hits is above 80%. They took a very important effect in the offense that allied country army launched in order to destroy the strategic targets of Iraq, and it attracted worldwide attention immediately. With regard to technology, it is one of the most remarkable new weapons of the modern world. Tomahawk cruise missile is the result of three key technological innovations. One of these key technological innovations is the application of scene matching missile guidance technology. Tomahawk cruise missile adopts the combination of terrain contour matching guidance and inertial guidance, this reduce the CEP (circular error probability) of hitting the target to about 30 meters. Moreover, the Tomahawk cruise missile with conventional warhead is equipped with scene matching terminal guidance system, which reduces the CEP to only meters. The SS-NX-21 strategic cruise missile, which is developed by the former Soviet Union, adopts a similar technology as Tomahawk cruise missile, achieves a close performance. In addition to the application in cruise missile, the scene matching missile guidance technology is applied in ballistic missile, a successful example is the Pershing II medium range ground to ground missile. After the warhead of the Pershing II missile reenters the atmosphere, it adopts the radar regional correlation terminal guidance system, that significantly improves the accuracy, CEP reaches to about 30 meters. Scene matching guidance is a kind of autonomous guidance. In addition to the applications in the medium guidance and the terminal guidance of cruise missile, the terminal guidance of ground to ground missile, scene matching guidance can be widely applied in automatic navigation system in manned and un-manned aircraft, such as the SPARTAN topographic reference navigation guidance system developed by British.

As early as in the 40's, the theory of topographical image correlation locating was unsuccessfully implemented to the application as automatic navigation system for aircraft, one example was the developing of the guidance system for the TM-76A missile. Because the limitation of available technology, the equipment was heavy and cumbersome, the precision of guidance was low, this theory can not be implemented in real

application. Later, in the 60's and the 70's, E System Corporation began a lot of researches and airplane hang tests. Till the end of the 70's, after many great progresses had been achieved in areas like remote sensing, microelectronics and precision measurement, the scene matching technology went into the reality of practical application.

Scene matching is a branch of image processing and pattern recognition. The theory of scene matching locating is not complicated, it simulates the locating process of human being ---- memorization, observation and comparison judgment. Scene matching guidance is selecting some kind of topography images with specific property in the mid-section or the end section of the missile's trajectory in advance, drawing those images into reference maps, storing those maps in the correlation processor of the missile computer. When the missile flies over those areas, the remote sensor in the missile measures the specific property value in real time, constructs the real time image. The real time image is compared to the reference image that stored in the computer earlier by the correlation processor, the most likely point that real time image locates in the reference image is then determined, this point is called matching point. From this matching point, the precision real time position of the missile is computed and determined, this information is applied by the guidance and control system to correct the trajectory in order to hit the target accurately. Scene matching guidance can utilize data from many kinds of the topographic characteristics, such as ground elevation, radar reflectance, infrared radiation and visible light images of different ground objects. There are many forms of scene matching guidance system such as terrain contour matching guidance, radar scene matching guidance, microwave radiation imaging matching guidance and infrared and visible light imaging matching guidance.

Because the scene matching guidance uses the large quantity of high resolution image data, its precision of guidance is very high, this is the advantage of scene matching guidance. Because the process of scene matching guidance is always used in the mid-section or close to the end of the trajectory. Especially if the scene matching guidance is applied in the terminal stage, it can be used to correct trajectory errors like target measuring error, initial launching error, accumulated inertial error, and reentry error, etc. It means that, in terms of theory, the accuracy of targeting is independent to the range. So the weapon's vuneralbility to the above mentioned source of error are lowered, that creates favorable conditions for the launching maneuverability and reentry maneuverability, enhances the abilities of survival and the surprise attack of the weapon system. Also because the matching guidance theory is the result of processing a great amount of image information with statistical decision making technology,

and most of these image matching guidance systems are combined with the inertial guidance to form a compound guidance system. Even if a radio image sensor is utilized by these systems, the scene matching guidance system still has great anti-interference ability. Moreover, it is economical. For example, the Tomahawk cruise missile whose kill and wound ability is two quantitative levels higher than the Militia III missile, but its total cost, including the maintenance cost of ten years, is one quantitative level lower than the Militia III missile.

The following chapters we will first analyze the terrain contour matching guidance system (TERCOM) of Tomahawk cruise missile and the radar area correlator terminal guidance system (RACTG) of Pershing II mediate range ballistic missile, and then, discuss the key technology of scene matching guidance and navigation technology and their development trends.

1. Terrain Contour Matching Guidance System of Tomahawk Cruise Missile

Tomahawk Cruise Missile is a multi-purpose and multi-launch platform advanced weapon system. It can be launched from sea, air and land based platform. It can carry nuclear warhead, also can carry conventional warhead. The Tomahawk cruise missile was put on active duty since 1983. In pace with Tomahawk Cruise Missile of the US, the Soviet Union developed the similar weapon, such as SS-NX-21, and AS-X-15 cruise missile.

The most outstanding advantage of Tomahawk Cruise Missile is its high accuracy of hitting. The circular error probability (CEP) of the strategic model, which adopts the combination guidance (including terrain contour matching guidance and inertial guidance), such as BCM-109A, is around 30 meters. The CEP of the conventional warhead model, which has digital scene matching terminal guidance, such as BGM-109C, is even higher, it can reaches the target within several meters. This kind of missile adopts flight by topography and obstruction evading technologies, the cruising altitude is between 45 meters and 100 meters, typically it flies 60 meters above ground. Therefore, this kind of missile has good surprise attack ability, despite the speed of the missile is low, only 0.7 ~ 0.85 Mach. Moreover, the fighting ability and vitality of this kind of cruise missile are enhanced greatly by the long range (reaches 2580 Km), the flexible trajectory, multiple launching platform, multiple choice of warheads, etc.

For a flight last as long as two hours, Tomahawk Cruise Missile adopts the mid-section guidance which is a inertial guidance amended by the terrain contour matching guidance. It assures that the missile flies following the pre-determinate trajectory exactly. Terrain matching is also called terrain contour matching (TERCOM). The theory is as

following. At first, using the photography that was taken by the satellite or aircraft, to draw the rise and fall of the terrain in the areas of pre-determined trajectory into digital reference maps, stored these maps into the missile computer before launching. The size and the ground resolution of the maps are different because of different guidance parameter, for example, the maps with size of 5 Km and 20 Km in length, resolutions are between 100 meters and 10s of meters. When the missile flies over this area, the altitude sensor such as the radar altimeter in the missile is opened to survey the rise and fall of the terrain and construct a one dimension real time map of topographic profile. This real time map and the pre-stored map are processed in the correlation processor, this is called correlation process. There are many kinds of correlation process algorithms, all those algorithms have the same goal, that is to find the maximum likelihood point that the real time map coincide with the same point in the reference map, this point is called matching point. Thus the accurate real time position of the aircraft can be computed. The three dimensional coordinate value that is calculated by terrain contour matching can be used to correct the trajectory, as well as can be used to calculate the drift of the inertia device, thus to improve the precision of the inertia guidance. If the cruise missile's flying time is more than two hours long, it is not enough to execute the terrain matching for only once. In practice, up to ten times or more of terrain matching is required to provide accurate targeting. The typical working process is that, after the Tomahawk cruise missile is launched from the platform, if it is launched from warship, the missile will keep minimum altitude flight on the sea, by means of inertia guidance completely. The missile will go on-shore after flying four hundred to five hundred kilometers, at this time, the missile will enter the first terrain matching area, do the first execution of terrain matching, it will correct the launching platform location error, and the inertia guidance error during several hundreds kilometers flight, etc. These errors are all somewhat big, for example, several hundred meters or even bigger. So the size of the land covered by the first reference image after the missile go on-shore is relatively big, such as 8 kilometers to 10 kilometers wide, about 20 kilometers long. After the missile go on-shore, there will be a terrain matching execution every 100 Km ~ 200 Km. Because the flying time between this interval is short, the error of inertia guidance is

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small, about 100 meters to 200 meters. Therefore, the size of the second, the third, and the following reference image could be relatively small. For example, 2 Km ~ 3 Km wide is enough. Due to the repeated intermittent

revision of inertia guidance by means of terrain contour matching guidance, the real trajectory of the missile appears zigzag, instead of a smooth ideal trajectory.

The terrain contour matching guidance system (TERCOM) which Tomahawk Cruise Missile equipped is provided by the McDonnell Douglas Corporation, the model is AN/DSW - 15, the precision of guidance is between 12 meters to 130 meters, total weight of the system is 37 Kg, total volume is 28 t. This kind of terrain contour matching guidance system including three subsystems, they are radar altitude meter, correlation computer and inertia platform. The radar altitude meter is AN/APN - 194 Radar Altitude Meter produced by the Honeywell Corporation. This is a kind of general purpose airborne radar altitude meter, working in C band, the power of broadcasting is 1 Kw, working altitude is 0 to 1500 meters. LC-4516C, the single instruction, single address model computer, produced by the Litton Corporation, is used as correlation computer. The word length of this computer is 16 bits, it also can finish double words operation, the clock frequency is 6.48 MHz, single addition costs 11.26 us, it can store more than ten digital reference terrain images. This terrain contour matching guidance system adopts the model LN-35 inertia platform system also produced by the Litton Corporation. It consists of a P-1000 four ring platform, a G-1200 gyro and a A-1000 accelerometer. The intrinsic precision of the platform is 0.9 km/h, it is a medium precision inertial device. The terrain reference images which this TERCOM system utilized are surveyed and drew by The National Mapping Bureau of the US through satellite photograph.

From the above introduction about the TERCOM system of Tomahawk Cruise Missile, we can see that all subsystems of this system, such as radar altitude meter, computer, inertial device, etc. are medium level, mature components. But due to the novel system design idea, they constitute the advanced, precise guidance system, this is the design tactics that we can use for reference.

2. Radar Area Correlation Terminal Guidance (RACTG) of the Pershing II Medium Range Ballistic Missile

The example of the application of scene matching guidance technology in ballistic missile is the radar area correlation terminal guidance of Pershing II medium range ballistic missile, that is RACTG. Pershing II missile is a kind of medium range ballistic missile which has the ability of mobile launching and maneuverable reentry. Its effective range can reach 2500 Km, the hitting precision CEP is about 30 m. It is improved on the base of model Pershing I A. The improvement is adding maneuverable reentry warhead, enhance the surprise attack ability and hitting precision, CEP is lower from 400 m to about 30 m.

The following is the working process of terminal guidance of Pershing II missile. After the warhead reenter the atmosphere, conducts the lift - drag flying maneuver. On one hand, it is advantageous to avoid being intercepted by the air defense, enhance the surprise attack ability, on the other hand, it will slow down the warhead, make the warhead fall to the target almost vertically at the end of the trajectory, create the favorable condition for the scene matching terminal guidance. When the warhead fall down to about 8 Km - 10 Km high, the radar area correlation terminal guidance will start working. At that time, the real aperture image radar antenna will begin a circular image scanning, the scanning frequency is 2 cycles per second, the center is vertical to the horizon, the target area is the dead center under the warhead. The circular radar image of target area is processed through geometric distortion correction, coordinate transformation and image pre-processing, and then is correlatively compared with the pre-stored reference images in the correlation computer, the best matching point at which the real time radar image coincide in the reference image is found, the precise position of the warhead relating to the target is calculated. This position information is used by the control system to correct the trajectory. The time for finishing image correlation is about 1 second, in which the former 0.5 second is used by the radar antenna to scan a circle to get the real time radar image, the later 0.5 second is used for correlation processing. The whole section of radar area correlation terminal guidance need 3 to 4 times such revision process till the warhead is 900 meter above the ground. After that the warhead will fall directly towards the target. These several times of correlation locating and trajectory revision, lowered the Pershing II missile's CEP of targeting to only 30 meters.

The radar area correlation terminal guidance system that Pershing II missile uses is developed by GoodYear Corporation.

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It includes a three degree of freedom stabilized image radar antenna, radar transmitting and receiving system, high speed correlation processor, power supply system, digital reference image, correlation processing software, radar antenna cover which is also acting as warhead's cowl. The main part of the radar area correlation equipment weights about 57 Kg without the radar antenna cover. This part is placed in the front of the warhead, among which the three degree of freedom antenna is in the antenna cover which has the good performance of wave transmitting. The image radar antenna is in the shape of cutting paraboloid, adopts the deviation focus forward feed horn illuminator to form a 2.2 * 22 degree sector wave

beam and assure that pitching wave beam (22 degree direction) deviates from the antenna rotation scanning center in a fixed angle. When the antenna scans the target area to get image, the rotation center of the antenna need to track the vertical line because of the different warhead postures. It means that the antenna need to do position and pitching follow-up. Thus this radar image antenna is a kind of stable antenna equipment which has three degree of freedom of position, pitching and rotation and equipped with three follow-up control systems. The image radar that Pershing II warhead terminal guidance system uses is a real aperture radar whose working frequency is in J band. The sender in this radar is a incoherent pulse magnetron sender, the success rate of sending pulse peak value is about 60 km. In order to improve the performance of this radar, the frequency sudden changing technology is used. The received ground echo wave signal is processed by direct frequency mixing, local oscillator uses sudden frequency changing tracking local oscillator with appropriate frequency. The logarithm intermediate frequency amplifier preserves the reflection system information of different land objects in big area. Besides the pre-processing and output data processing, the main computing task of the correlation computer is correlation operation. For example, the pixels of the real time radar image are 128 * 128 matrix, the pixels of the reference image are 256 * 256 matrix, the computing quantity of finishing a whole image searching need 270 million operations, if it is necessary to finish this amount of computing within 0.5 second, the computer speed will be more than 500 million operations per second. Even the simplest correlation algorithm is used, such as Mean Absolute Difference (MAD) algorithm, and with effective speedy searching algorithm which cut the computing burden significantly, the computer's speed should be more than 50 million operations per second. In the 70's, because of the application difficulty of the computer technology in the missile, an optical correlation device was used instead. Later, the all digitized correlation processor took place of the optical correlation device. To achieve the processing speed of 50 million operations (addition) per second in the missile, it is impossible to imagined with a single CPU computer at that time. So, we can deduce a conclusion that its correlation computer uses multi CPU parallel connecting technology, or array computer technology. The radar reference images that this radar area correlation processor uses are made by the automatic reference map generating equipment which is developed by the GAC Corporation. This equipment uses the standardized database DLMS produced by National Defense Mapping Bureau of the US, the designated target area, and the radar parameters in the missile to generate the radar reference image which can be stored onto the memory in the missile's correlation computer. The reference image is supplied to the user in form of magnetic

tape and is installed into the missile's correlation computer before launching.

3. The Key Technologies of Scene matching Guidance

From the above mentioned scene matching guidance system which Tomahawk cruise missile and Pershing II missile use, we can see some basic construction features and key technologies of the scene matching guidance system, the following is the conclusion.

3.1 Scene matching Guidance System

The basic components of the scene matching guidance system in the missile include image sensor (such as image radar or infrared imaging device), image correlation processor, digital reference image, correlation processing software, inertia measurement device, guidance computer and control system, etc. The ground equipment which coordinates the missile should include the highly automated testing equipment and the high performance ground supporting computer to quickly finish the test of the missile guidance system, the algorithm optimization, the installation of data and programs and other jobs, all these work must be finished in a limited time before launching.

In practice, as a weapon system, the scene matching guidance system need a strong rear service maintenance system. The process of surveying the target by satellites, drawing reference images, installing target parameters and reference images into ground supporting computer, is very complicated. It is particularly in the war time that the renew of the target reference images, shows the importance of this maintenance system. Therefore, we can say, the scene matching guidance system is also a new weapon system supported by the modernized comprehensive technology.

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3.2 Real Time Remote Image Sensor

There are a great variety of remote image sensors used in the missile to survey the real time image. If we classify them by the type of the surveyed real time image, there are terrain image sensor, microwave radiation image sensor, radar image sensor, infrared image sensor, visible light image sensor, astronomical image sensor, magnetic field sensor, etc.

The sensor used in surveying and drawing the terrain image always employs microwave radar altitude meter, it has the all weather capacity, the range of height measuring is big, the adaptive ability to the aircraft's flying orientation is strong. But the microwave signal

reveals itself easily is the drawback. If the laser altitude meter is used to measure the rise and fall of the earth surface, it has strong hidden ability. But the laser beam is narrow, the adaptive ability to the aircraft's flying orientation is poor, and the laser is not capable for all weather operation.

To measure the microwave reflectivity of different earth objects to construct the radar image, the typical sensor being used is microwave imaging radar, such as the J band imaging radar being used in Pershing II missile's terminal guidance. Due to the limited missile pay load, small volume, light weight, put a tremendous limitation on the way of guidance system (including the missile-target coordinate relationship), the missile synthetic aperture imaging radar has some significant technological application difficulty. Therefore, the real aperture imaging radar becomes the primary selection. It has been mentioned before that due to the limitation of the missile pay load, the aperture of the radar antenna can't be very big, it limits the resolution of the target radar image, negatively affects the precision of the missile's guidance. In order to raise radar's resolution to get more clear images, the high band radar has been developed, the um wave imaging radar is a typical one. The 8 um, even 3 um wavelength millimeter wave radar has the resolving power closing to the optical sensor, the all weather capacity closing to that of the microwave band radar, so it is a fairly ideal image sensor, and is aggressively developed in other countries. Till now, the short range um wave imaging radar in other countries has been quietly mature, the long range missile um wave imaging radar is still in developing. The imaging radar we have mentioned above are all active radar, it radiates the electromeganetic wave, could be revealed easily. Thus the passive microwave imaging radiometer becomes relatively superior real time image sensor. It scans and receives the microwave energy being radiated by the different surface objects themselves to construct the microwave radiation image. The radiometer itself is only a receiver, it doesn't radiate energy, so it's easier to avoid exposure. Because ground object radiates little microwave energy, it is necessary that the sensitivity of the radiometer receiver is very high. Even though, it is very difficult to use as long range imaging sensor, but for short range microwave radiation imaging, it has been in the practical application stage.

In order to gain the high targeting accuracy, in the end of its trajectory (this is also called the target area), the Tomahawk cruise missile which carries the conventional warhead also deploys the optical digital scene matching terminal guidance technology, which makes this kind of missile reaches an over 2000 km distance target off only a few meters. This terminal guidance uses the television camera as the optical real time image sensor. The television camera which uses charged couple device

(CCD) with very high image resolution, it is a matured technology. The weakness is that it can't be used at night, which lowered its practical application. Thus the infrared imaging digital scene matching terminal guidance is developed for Tomahawk cruise missile. With the development of multiple unit infrared devices, the infrared imaging guidance has gradually been in practical application stage. There are two kinds of the infrared sensitive devices of the infrared image sensor being used in scene matching terminal guidance, one is the imaging method using multiple unit array (such as the infrared CCD array) plus mechanical scanning, the other is multiple unit surface array (such as the infrared CCD surface array, also called staring infrared imaging system). The staring infrared imaging system technology is still in its research and trial stage. The infrared imaging sensor overcomes the optical sensor's weakness that can't be used at night. Especially due to the advancement of the far infrared devices, the infrared imaging has the night vision capacity with very high sensitivity. In addition to the high precision of matching locating due to the high resolution power, the visible light and infrared imaging system are all passive receiving system, so they have very good hiding ability, and the equipment is light and handy. But as the optical sensor, they don't have the all weather capacity. So, they usually are used in the low speed aircraft, or short range scene matching guidance sensor.

In order to resolve the problem of precise guidance above the sea which have no terrain information to use, the earth magnetic field contour matching guidance is put forward and tested, this is what is called MAGCOM. The sensor this system uses is magnetic field sensor. Due to the difficulty of the earth magnetic line data acquisition

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and the problems associated with the practical application of MAGCOM, till now the magnetic contour matching technology can not get into practical application. Another similar system is gravitational field contour matching guidance, it utilizes the gravitational field or its abnormality to realizing the locating, the sensor it employs is gravitational field sensor. So far this is also an immature technology.

3.3 Image Correlation Processor

The missile correlation processor need to accomplish the pre-processing of the remote sensor's data, real time imaging, coordinate transform, geometric distortion correction, motion compensation, image correlation computing, and data filtering of the aircraft position, etc. The largest computation task is the correlation computing.

Because of the low flying speed, the TERCOM system which is used in

the cruise missile's guidance has relatively more time to carry out correlation processing. Moreover, the TERCOM technology uses the correlation between the one dimensional terrain profile image and the two dimensional reference image, the computation amount is small compared with the two dimensional real time image method. The TERCOM system in Tomahawk cruise missile employs a single CPU computer. It means that the single CPU computer with speed ranges from tens of thousands to about one million operations per second can perform well.

The area correlation system employs the plane correlation between two dimensional real time image and two dimensional reference image, so the demand for the correlation processor is much more. For example, as for the real time image of 128 * 128 array and the reference image of 256 * 256 array which have been mentioned in chapter 3 of this paper, if we need to finish the correlation computing in 0.5 second, the computer we use must have the speed as high as 500 million operations per second, even if we employ the fast algorithm, the speed still need to be as high as 50 million operations per second. To achieve this high speed, the commonly used method is to employ array technology, that is using multiple CPU to construct the array computer, distributing the computation load, thus achieving the high speed of the whole computer. Currently, there are many kinds of high speed signal processing microprocessor on the market, such as the TMS 320 series produced by Texas Instruments, the i860 series by Intel, the Transputer series by Zmons, the DSP series by AD, all these processor could be used as the CPU chip of the array computer. Because the most operations of the correlation computer is the correlation processing between the real time image and the reference image, a great quantity of, the most repeatedly computation is the correlation computation of a pair of corresponding pixels in the two images, for example, the MAD algorithm is to compute the absolute difference of the two pixels' values. For this reason, if we use some special purpose CPU chip, such as the CPU which has the special instruction to compute the absolute value of the difference of two pixels as mentioned above, the array computer will be more efficient, the correlation processing time will be shorter.

Now a new type of photoelectric processor emerged. As for the correlation processing between the two images which has the greatest computational amount, it uses optical processor, as for other processing, such as pre-processing data, imaging, correcting, compensation, and filtering, etc., it uses digital processing method. In this way, it utilizes the high speed characteristic of the optical processing, also utilizes the flexibility of digital processing. We can see that the photoelectric processor is a kind of very practical processing system.

3.4 The Refe   rence Map (Image)

The reference image used by the scene matching guidance is usually drawn from the aerial photograph or the satellite photograph.

The digital terrain reference images used by the TERCOM system adopt the aerial photographs or the satellite photographs which have some overlap (for example more than 60% overlap). They utilize the visual principle of human being, recover the three dimensional model in the three dimensional coordinatograph, compute the elevation value of every sample, after geometric distortion correction, projection transformation, interpolation and other processing, form the digital terrain reference image with the designated surface resolution power and elevation precision. At last, the reference images are supplied to the military in form of magnetic tape.

The produce of the reference image used in the area correlation matching, such as the radar image reference image used in the radar scene matching guidance system, is more complicated than that of the terrain reference image. It is reported that, the reference image used in Pershing II missile's radar scene matching terminal guidance is made by the automatic reference map generating equipment which is developed by GAC Cooperation, using the aerial photograph or the satellite optical photograph. This equipment utilizes the standardized database DLMS, also called digital large land system database, produced by National Defense Mapping Bureau of the US. The DLMS database includes the digital terrain elevation database (DTED) and the digital feature analysis database (DFAD). After the target area or the area need to be mapped has been chosen, utilize the DLMS database, the radar reflectance coefficients database, the target area radar reflectivity database, take into account the geometric relationship between the missile's pre-loaded images radar and the earth surface,

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the antenna's pattern, the receiver's parameters, etc, model and transform the attained radar reflectivity data, at last we can get the target area's reference map which could be installed into the image correlation processor.

If the real time image and the reference image used in the image correlation don't directly utilize the (grey scale) image of the earth's objective, but utilize some characteristics of this image, such as the boundary characteristic of different objectives, thus the reference image used in correlation processing is characteristic reference image, drawing this kind of image is much easier. For example, to directly produce the edge characteristic reference image of different objectives' boundary

from the satellite optical photograph is much easier. We need only to input the optical photograph into the computer, the computer will directly pick up the edge characteristic information and generate the edge characteristic reference image.

3.5 The Image Correlation Processing Software

The main task of the correlation processing is to find the most likelihood position where the real time image which is gathered by the missile remote sensor, coincides in the reference image, this position is called matching point. The computation of looking for the matching point of the real time image in the reference image can be divided into two problems, one is measurement function problem, the other one is searching method problem.

Measurement function is a function used to compute the degree of familiarity between the real time image and the sub-area image in the reference image. There are many kinds of measurement function, the principle of the selection is effective and simple to achieve the high capture probability (correctly matching probability) and spend as little computational time as possible. The typical measurement function is the product method (prod), it calculates the mean value of the product of the corresponding pixels in the real time image and the sub-area of the reference image, this mean value acts as the criterion for the correlation value. The measurement function's computation algorithm of the normalized product method is shown as the following equation:

equation (7-1)

where M N --- the size of the real time image;

R, , ---- reference image, mean value, variance

S, , ---- real time image, mean value, variance

For (I, J) sub-area in the reference image, when D (I, J) reaches its maximum, this position is the matching point. The product method, in a word, is to compute the correlation coefficient directly. Because the multiply operation spends rather more computer time, the simplest algorithm to compute the distance of two sets is the mean absolute difference (MAD) algorithm, it only computes the absolute value of the difference between a pair of pixels. The next simple algorithm is mean square difference (MSD) algorithm, it computes the square of the difference between a pair of pixels. These three algorithms have the statistical internal relations, and have the nearly same performance index, so the MAD algorithm is been selected firstly because of its simplicity. There is another very simple logical algorithm, called the algorithm, when comparing every pair of pixels in the real time image and the reference image, if the pixels have the same value, set the

measurement value to 1, else set it to 0. This algorithm's performance is not as good as the three algorithms that have been mentioned above for the multiple levels image. But for the two levels image, it is the same as those three algorithms, they have the same truth table. In addition, for different application situations, the amplitude ordering correlation algorithm, the paired function algorithm and other algorithms, have suggested many distinguishing similarity computation methods.

For a sub-area in the reference, the above-mentioned measurement function gives an evaluation data, only when the similarity computation between all the sub-areas in the reference image has finished, can we get the result for the most likelihood sub-area as the matching point. The process that computes the one by one for the sub-area's similarity of the reference image is what called searching process. The searching method should be selected to be effective and quick. In order to finishing the searching process for the whole reference image quickly, the main method is to cut the unnecessary computation amount as more as possible. For example, a kind of sequential similarity evaluation algorithm (SSDA) which is suitable for the mean absolute difference algorithm can reduce the computation amount several fold. The principle of this algorithm is, for the non-matching point conducting little coarse computation and evaluation, but for the possible matching sub-areas conducting fine computation and evaluation. Thus to cut the cost, enhance the correlation processing efficiency greatly. Another example is the coarse and fine variable resolution sequential similarity evaluation detection method usually used in the two dimensional real time image correlation processing, the first step is to search in the coarse reference image whose resolution is low,

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because of the low resolution, the reference image pixels matrix is smaller for the same target area size, so the whole image searching time is short. The second step is to use the fine reference image whose resolution is high, but conduct fine searching only near some few possible matching points which are found in the first step to determine the true matching sub-area at last. Of course, we can conduct three or four steps variable resolution searching. This kind of coarse and fine variable resolution method can save computation amount, enhance the correlation processing efficiency greatly, reduce the correlation processing time.

Characteristic matching algorithm is a commonly used method in the scene matching guidance and navigation. In practical application, the mechanisms of the real time image and the reference image are possibly different. For example, the above-mentioned Pershing II missile's

terminal guidance system, its reference image is drawn from optical photograph and its real time image is drawn by the imaging radar, these images with two different mechanisms are very different in grey scale. It is a problem to conduct the correlation processing directly using images from these two different mechanisms. Moreover, due to the variance of all kinds of environmental factors, the real time image is not stable, it also brings problem for the image correlation. Therefore, the matching method to get the similar characteristics in the real time image and the reference image becomes an effective way to solve the above-mentioned problems, at the same time, it can reduce the computation amount, enhance the anti-interference ability. The edge characteristic is the most commonly used characteristic. The image edge is the natural characteristic due to the different reflection coefficients of the different targets, it is stable, and for the different mechanism images, their edge characteristics are similar, so the edge characteristic matching is extensively used in the scene matching guidance. In addition to the method that directly utilizing the edge characteristic to do correlation processing, there are many other kinds of methods to utilize the edge characteristic. For example, computing the Hough transform of the edge, doing the correlation processing in the Hough space, it is possible to enhance the correlation processing speed. Besides the edge characteristic, there are many other kinds of image characteristic to utilize, such as after the two dimensional FFT transform of the image, the phase characteristic of the frequency domain also could be used in the matching guidance.

3.6 The system Technology

The performance evaluation and the error analysis of the image correlation are the foundations of the scene matching guidance engineering design. The performance of the scene matching includes two aspects, they are effectiveness and confidence. The indicator that reflect the effectiveness include the locating precision of the scene matching point, the computation amount of the image correlation processing or the processing speed, etc. The indicator that reflect the confidence include the correct catching probability of the true matching point, the false locating probability that the mismatching point is misjudged to the matching point, etc. There are many factors to affect those performance, such as reference image characteristic, correlation algorithm, flight parameter error, image remote sensor measurement error, reference image mapping error, geometric distortion, and image resolution, etc. The influence to the scene matching performance of all kinds of factors is the foundation of the parameter analysis of the scene matching system and its subsystem. The digital emulation of the scene matching guidance

technology is also the effective method to study and test the system design.

We have mentioned above that the image correlation system usually coordinates with other guidance systems, such as the inertia navigation, and the Loran navigation, etc. to construct the combined guidance or navigation system. So the research of utilizing the image correlation to form the best combined guidance mode is also the important research topic in the system technology.

3.7 The Supporting System of the Scene matching Guidance

The target information system conducts the measurement of the target, the identification and the parameters surveying and drawing. For the cooperative target of navigation, we can use the conventional multiple channels, but for the non cooperative target under attack, mainly use the satellite or the airplane to map. Satellite reconnaissance and the reference image automatic generating system are the primary tools for mapping the target area and the intermediate area. The library with great amount of initial reference images is administered by the professional surveying and drawing department, stored in the magnetic tapes or disks to supply to the user, the user creates the small library of the reference images in the area that will be used most frequently.

The launching commanding system in the platform works out the flying task that the aircraft will fly from the launching or taking off point to the target, installs and sets up the flying parameters, makes the program to run, pre-processes and sets up the reference images in the per-determined trajectory or intermediate area of the lane and the target area, conducts the automatic test of the scene matching guidance system and other preparations before the flying, thus to ensure that the aircraft will be guided to the target correctly and reliably.

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4. The Developing Trends of the Scene matching Guidance and Navigation Technologies

4.1 Multiple Sensors Combination

In order to enhance the adaptability of the aircraft, the anti-interference ability and the weapon's surprise attack ability, the sensor of the new model scene matching system employs a combination of systems. For example, the combination of the active sensor and the passive sensor. The active sensor is effective and autonomous, the passive sensor has the strong hiding ability, suitable for the surprise attack. Another example is the combination of the optical sensor and the electronic sensor, it can be called a ideal combination system. For example, the high resolution of

the infrared imaging sensor can enhance the guidance precision, the passive working mode of the infra-red device is suitable for the anti-interference, and hidden from enemy attack; the all weather capacity and long range of action of the microwave radar is suitable for the adaptability of the weapon system. The optical and the electronic system draw on each other's merits and give full play to each one's own strong point, thus greatly enhance the performance of the scene matching guidance system. This kind of multiple sensors combination system can be installed in the aircraft to work simultaneously or time-sharingly, or installed only one kind of sensor in a aircraft, but can change the sensor in the ground when it is necessary.

4.2 Intellectualization

The aircraft which employs the scene matching guidance and navigation need different reference image for the different flying destination or target. The instability of the real time image and the reference image brings many difficulties for the guidance system, it has very high demand especially for the ground supporting system. The more advanced scene matching guidance system do not require store many reference images in the aircraft's correlation computer in advance, it employs the intellectualized identification method to finish the locating and the navigation. First, it need to set up the target area knowledge base on the basis of a great deal of study in advance for the target's images in all kinds of conditions. In the period of the aircraft's flying guidance, it identifies and locates the target according to the real time image measured by the remote sensor and the knowledge base of the selected target area, conducts the precise guidance. Thus, it need not to pre-store the reference images in the aircraft and avoids the trouble of renewing the reference image due to the condition changed.

4.3 The New Method for Scene matching Location

The range only correlation system (ROCS) is a simple construction, small size, light weight, low cost, and high precision new guidance system. The working principle is similar to the principle of the multiple point ranging locating. On the basis of the slope distances between the aircraft and three or more previously selected ground correlation areas, the geographical position of the aircraft can be calculated precisely. For each correlation area, the amplitude trace of the radar return wave is called the A-trace, it is determined by the terrain and object characteristic in the area that be irradiated by the radar wave beam, and the slope distance between the aircraft and this area. This A-trace is compared with the previously stored reference image of this area (correlation processing) to determine the A-trace's position in this

correlation area, thus to determine the aircraft's slope distance relating to this area. Similarly, the other two or even more slope distances could be calculated. At last the aircraft's precise position is calculated. The radar antenna of this kind of system does not scan, it is simple, small and light, the cost is low. Because the real time image used in the correlation processing is one dimensional A-trace, the processing speed is high, the locating precision is also high, the adoption of radar remote sensor makes the system able to operate in all weather. But due to the difficulty to draw the ROCS system's A-trace reference image, and the need that the wave beam of the radar's fixed antenna in the aircraft must irradiate the selected ground correlation area, there exists many difficulties in the engineering implementation.

About the above-mentioned terrain contour matching guidance system (TERCOM), if we get the locating information of the aircraft, and process the data through the Kalman filter, we can get good navigation performance. The Sandia Inertial Terrain-Aided Navigation (SITAN), developed by the Sandia Laboratory, can get the best performance of the terrain-aided navigation. The principle of this method is to compare the terrain elevation difference practically measured by the aircraft's radar with the terrain elevation difference that is computed using the previously stored terrain image, their difference are processed by the Kalman filter to produce the error status estimation of the navigation system.

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This is a new continuous processing method, it will improve the navigation precision from emulation test and flying test, under all kinds of conditions, the CEP of the navigation could be less than 50 meters or even less, say 10 meters to 20 meters. The SITAN system has the same advantage of simple equipment as the TERCOM system, but its computation amount of recursive real time processing is much less. It allows the aircraft conduct maneuver flying within the reference image area. The SITAN system need a previously determined identification point with enough precision to meet the initial status need when the Kalman filter begins to work, thus to avoid the divergence. Therefore, it could be considered to combine the SITAN system with other navigation systems, such as TERCOM or GPS and so on, to determine a relatively more precise initial identification point.

4.4 Compound Guidance and Navigation

The compound guidance is the main method of realizing modern precise guidance technology. This method is to combine different guidance systems with different characteristics, rationally and organically, to give full

strength of each individual system under their favorable conditions, thus the whole guidance or navigation system gains the best performance. The above-mentioned terrain contour matching guidance system, radar image correlation matching guidance system, range only correlation system, Sandia inertial terrain-aided navigation system and so on, are all the obvious examples of utilizing the ground information and the inertia combination guidance or navigation method. The TERCOM system which utilizes the stable terrain information can not be used in a flat plain area, and the combination of the terrain guidance and the scene matching guidance could overcome this weakness and get more extensive application. The compound guidance system combines the scene matching guidance (which utilizes the ground information) with the star light guidance, could be used in the aircraft with both land and sea flying path. The combination guidance system combining the scene matching guidance and the Loran navigation system, or the scene matching guidance and the global position system (GPS) has been in the practical application period. In a word, the compound guidance system which organically combines the guidance systems with different mechanisms, learn from each other's strong point to offset each other's weakness, thus make the whole guidance or navigation system more perfect, performance better, so it is the main way to advance the modern guidance and navigation technologies.

Conclusions

The scene matching guidance and navigation is a kind of advanced active navigation technology, because it utilizes the terrain image information, it has the strong points of high navigation precision, irrelevant to the range, and all weather capacity, etc. It can be extensively used in all kinds of missile's guidance, the automatic guidance of the manned or unmanned plane and so on.

This paper gives a outline of the scene matching and navigation technologies in foreign country, which is only based on the references we can obtain. So if you want to do further research, please refer to the reference documents.

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